SWOT

Surface Water Ocean Topography

Science and Applications of Space-based Surface Water Observations

Aaron Boone* and the SWOT Working Group

* CNRS-GAME

Centre National de Recherches Météorologiques (CNRM) Météo-France

Toulouse, France

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

METEO FRANCE

Toujours un temps d'avance

SWOT Hydrology Questions

(SWOT Workshop, Ohio State U., Sept., 2008)

- **Water Cycle:** What is the spatial and temporal variability in the world's terrestrial surface water storage and discharge. How can we predict these variations more accurately?

- **Floodplains & Wetlands:** How much water is stored on a floodplain and subsequently exchanged with its main channel? How much carbon is potentially released from inundated areas?

- **Society:** What are the policy implications that freely available water storage data would have for water management? Can health issues related to waterborne diseases be predicted through better mappings?

SWOT *Science and Applications* ➔ Overview

In order to address the science questions, SWOT needs to measure/provide global estimates of:

<u>Level I</u> (primary, directly measured) quantities:

• *h* (*dh/dt*), *dh/dx*, *A* ➔ inundated floodplains, river channel widths

<u>Level II</u> (secondary, derived)

• Discharge (*Q*), *dQ/dt*, Storage change *dS/dt*

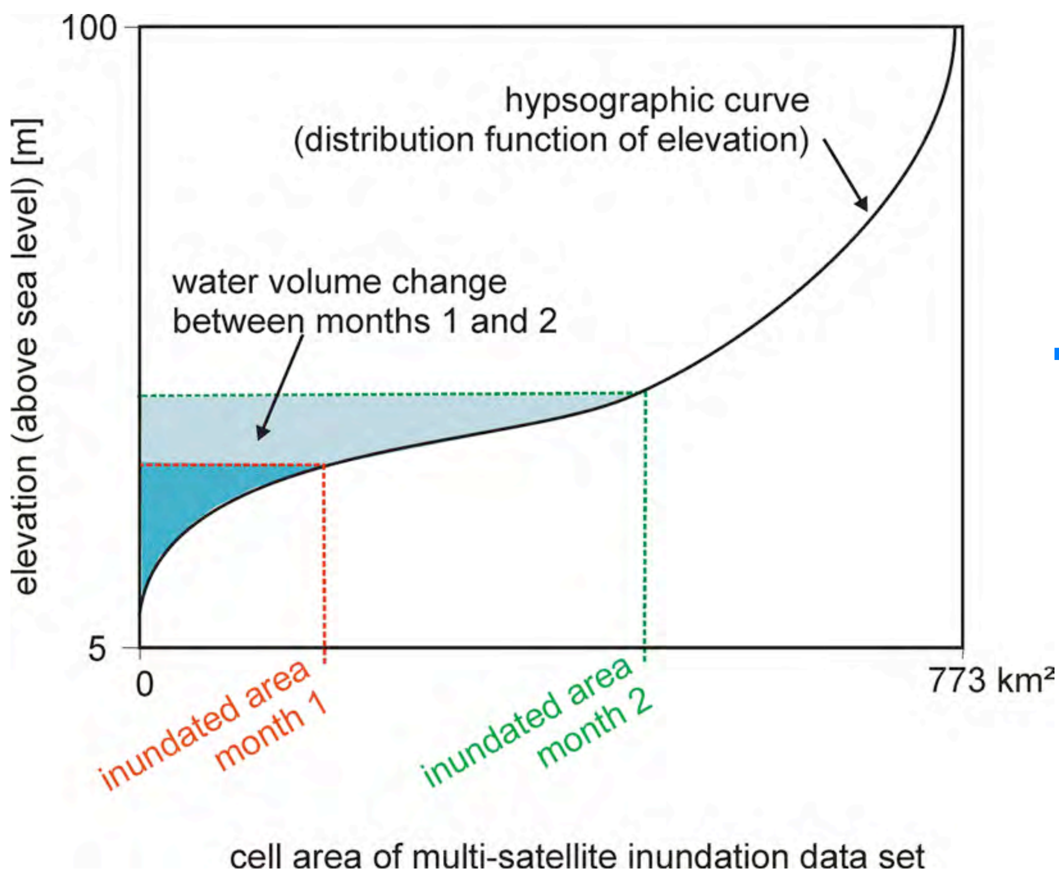
With time, possibly develop datasets/algorithms for:

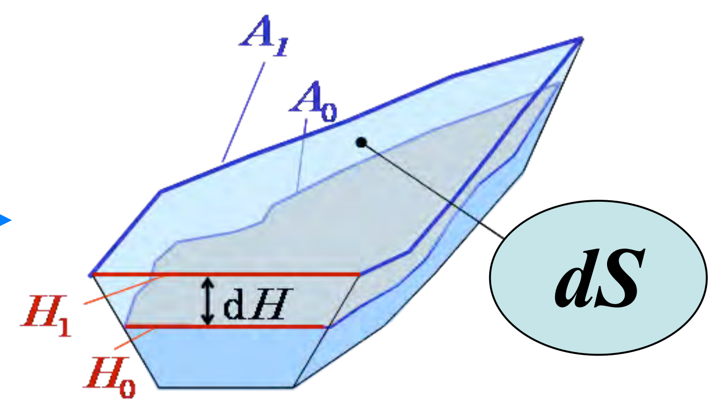
• Channel depth, lake inventory, more detailed DEM…

Current work: refining error estimates (esp. Related to temporal sampling and spatial resolution), assuring that accuracies needed for specific applications be attained

Example of obtaining storage change:

Using *dH/d*t, *dA/dt* and good quality DEM (*H* vs *A* relationship)➔ robust estimates of *dS/dt* are possible





SWOT *Science and Applications*

Science Applications - Given temporal and spatial sampling of SWOT:

1) Hydrodynamic

2) Hydrological - Hydrodynamic Modeling

3) Lake and wetland dynamics

4) Integrated Water Cycle Modeling

5) Society : Data on unmonitored (remote) basins, reservoirs, transboundary basins…

Such models and datasets permit the study of:

• Impact of anthropogenic change (dams, landuse change…)

• Impact of climate change on future water resources

• Flood monitoring (large, longer time scale floods)

• Water management strategy, policy

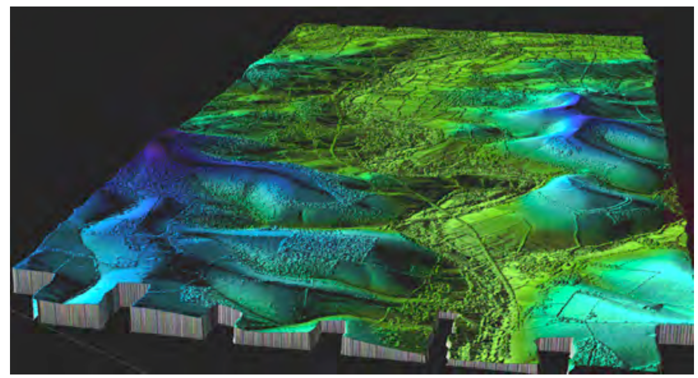
SWOT *Science and Applications* → 1 Hydrodynamic Models

- Principal tool for assessing flood risk
- Provide dynamic predictions of water depth and velocity
  - Horizontal scales of ~1-1000 m
  - Temporal scales of ~minutes over events lasting up to 1 year
  - Domain sizes of ~1- 100,000 km2
  - Can be 1, 2 or 3 dimensional (but consensus that floodplain inundation is at least a 2D process)

- When we have distributed cal/val data we can do great modelling, **But** …..
  - Existing gauges only test bulk flow routing
    - Allows modellers to 'get away with' 1D codes
  - We only have data to test 2D model performance at ~10-15 sites globally
    - Even here often only 1 flood extent image per event
    - Doesn't allow us to test 2D model dynamics
  - Lack of sufficient cal/val data means that many flood models suffer from high uncertainty

Model data needs:

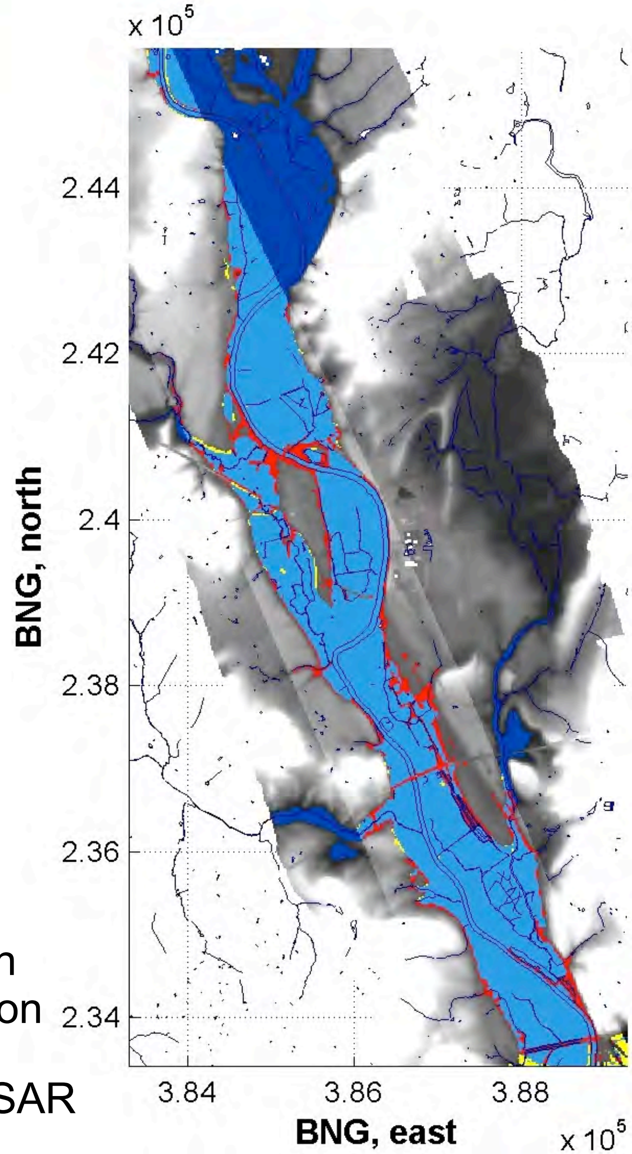
- Boundary conditions
  - Discharge and stage at river gauging stations
- Topography
  - Ideally LiDAR (<10m spatial resolution, <10cm rmse vertical accuracy), but can also use SRTM for large rivers
- Calibration/validation data
  - Measurements of water height and flood extent
  - Used to calibrate model friction parameters



P. Bates

SWOT Science and Applications → 1 Hydrodynamic Models

Upton on Severn, UK – 18m model vs airborne SAR

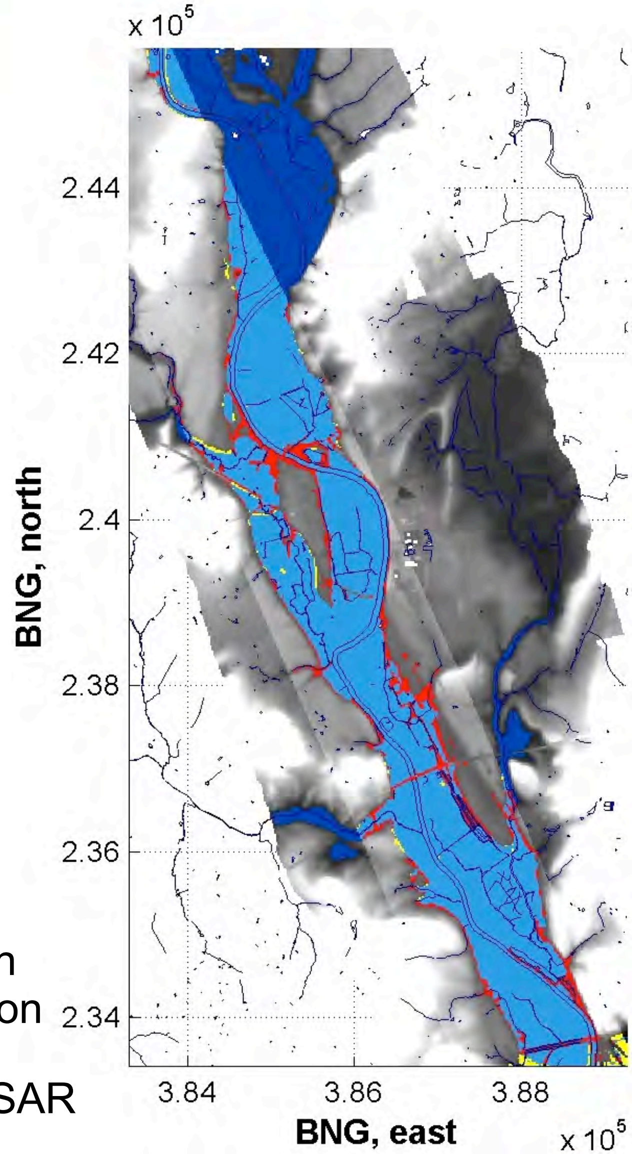


- = correct
- = over-prediction
- = under-prediction
- = predicted as flooded, no ASAR coverage

METEO FRANCE
Toujours un temps d'avance

SWOT Science and Applications → 1 Hydrodynamic Models

Upton on Severn, UK – 18m model vs airborne SAR



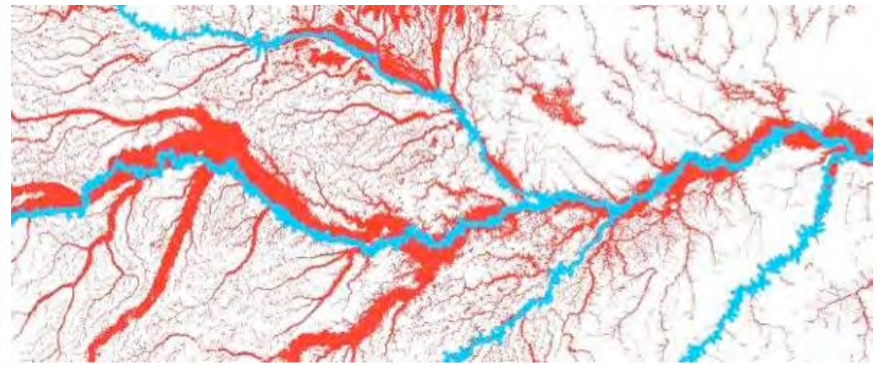
- = correct
- = over-prediction
- = under-prediction
- = predicted as flooded, no ASAR coverage

- **Must have ….**
  - Flood images at more sites than we currently have
    - Need flood extent at ~100m or less
    - Water elevations to centimeter level accuracy
  - For a smaller number of sites we need multiple SWOT images through events
    - Test model dynamic predictions
    - Will lead to the development of better modelling tools
- **Added value products…**
  - Discharge measurements in ungauged rivers accurate to ±25%
  - Better global floodplain terrain data (global scale!)

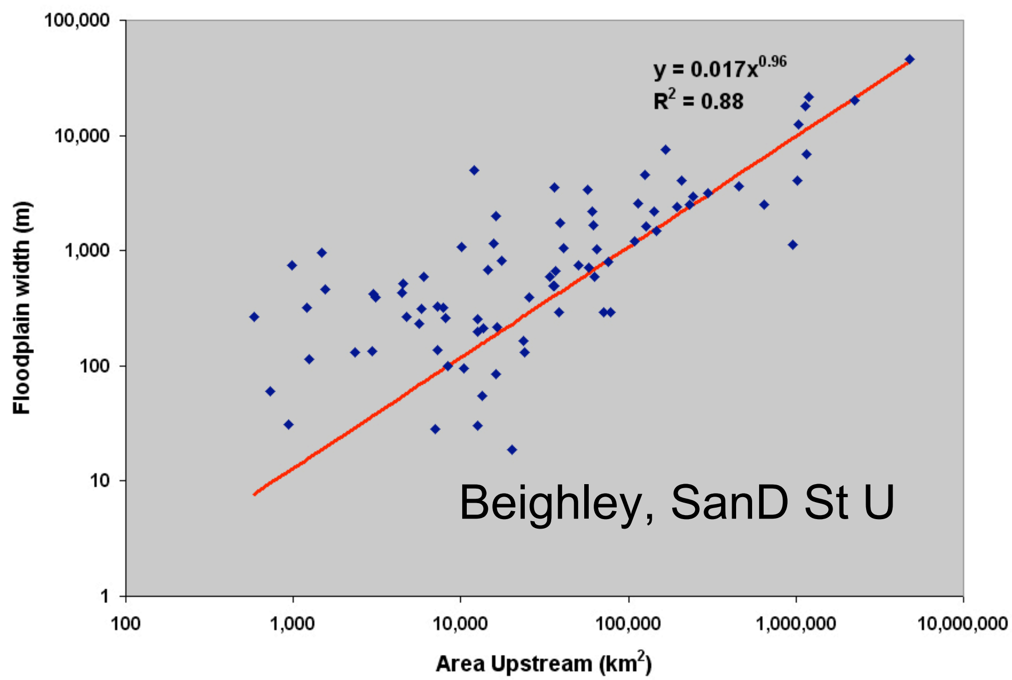
SWOT *Science and Applications* ➔ 2 Hydrologic-Hydrodynamic

Model Parameter Estimation: an example for river width

Our simulated channel and floodplains



Hess et al., 2003

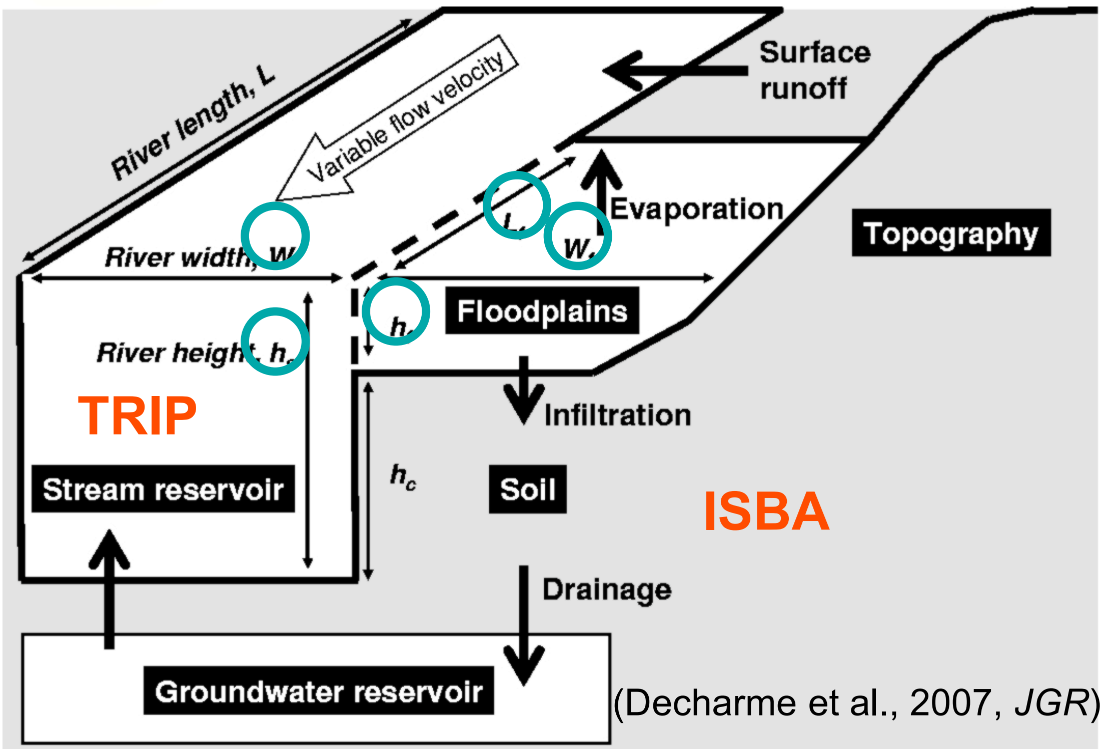


Current approach (floodplain vs upstream drainage area) , does not fully capture local variations NOT governed by drainage area alone

Reduced floodplain widths impact model results by **increasing flow depths** and **velocity** to handle discharge

SWOT Science and Applications ➔ 2 Hydrologic-Hydrodynamic

GCM-hydrology: ISBA-TRIP



(Decharme et al., 2007, *JGR*)

Key variables from SWOT

Key scientific question for SWOT: better quantify the echange between rivers and floodplains for improved prediction

<u>Development Methodology</u>

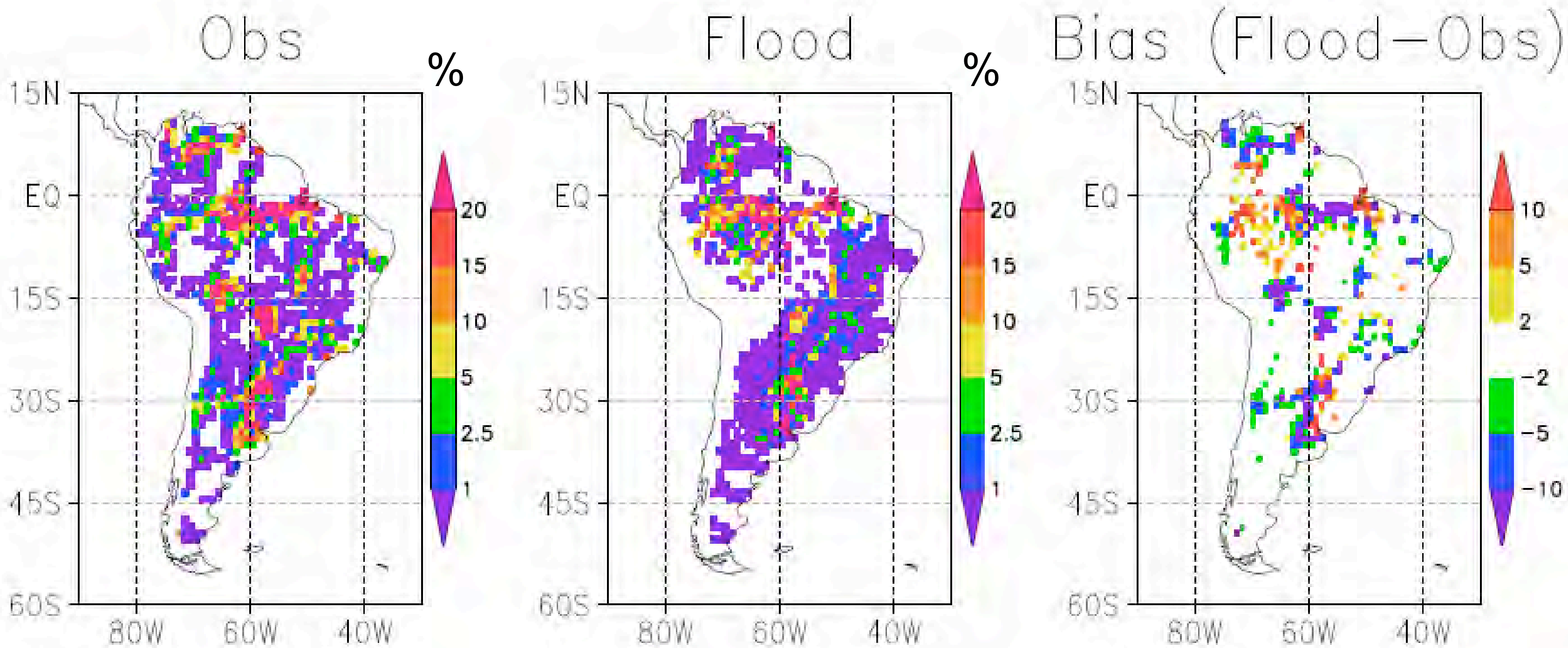
1) Improve in « offline » mode ➔ validation with obs and/or assimilation

2) Use in (fully-coupled) projection ➔ extrapolate in n,t !

* NEED Global scale data!

SWOT Science and Applications → 2 Hydrologic-Hydrodynamic

Spatial comparison between the Flood experiment and the Satellite-derived wetland estimates



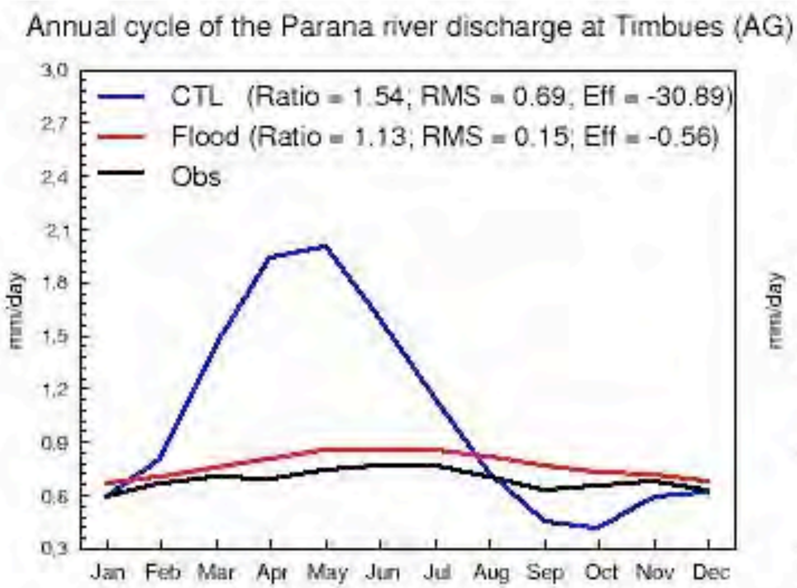
Satellite-derived wetland estimates from Prigent et al. (2007, JGR).

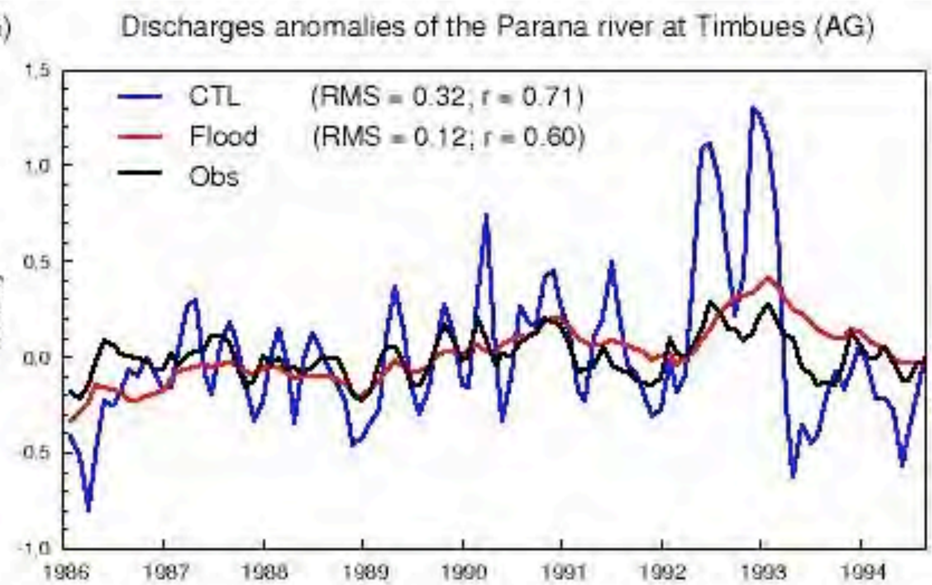
ISBA-TRIP flood-plain simulation

Difference

SWOT *Science and Applications* → 2 Hydrologic-Hydrodynamic

2 simulations (10-years atmospheric forcing from GSWP-2 at 1° by 1°):
with (Flood) and without (CTL) the flooding scheme





• Evaporation from floodplains quite significant for some regions: possible feedbacks with atmosphere…

GSWP-2, Dirmeyer et al., 2006

SWOT Science and Applications → 3 Lakes, Wetlands

Regional Lake management in different perspectives depending on:

- climate condition and variability (Arid, Semi-arid, mountaineering, tropical …)
- water uses purposes (supply for population, industry, agriculture, fishing tourism, navigation)
- Geopolitical issues: Transboundary water management

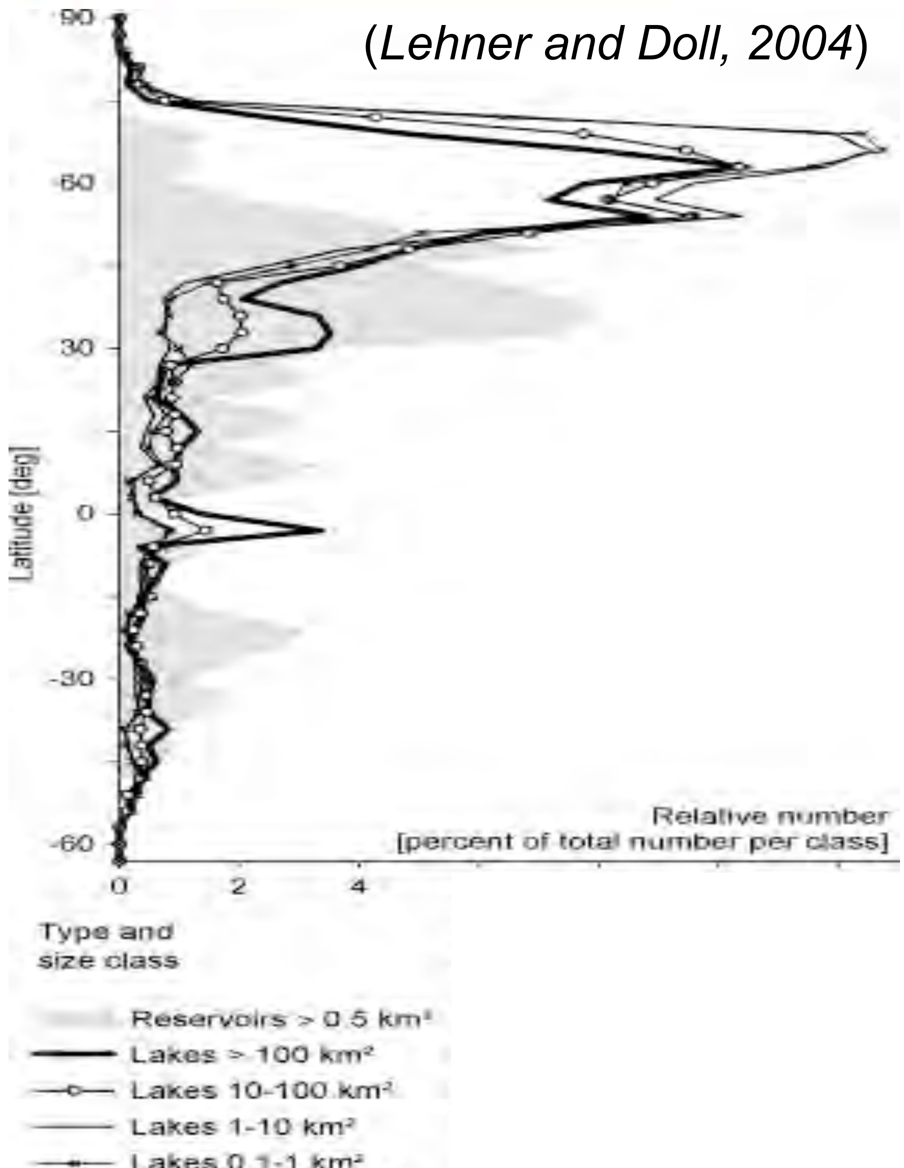
Global scale: Multiple Interactions and issues with

- hydrological water cycle
- Carbon and Methane storage and emission
- impact of artificial reservoirs on Global Sea Level Rise

End users:

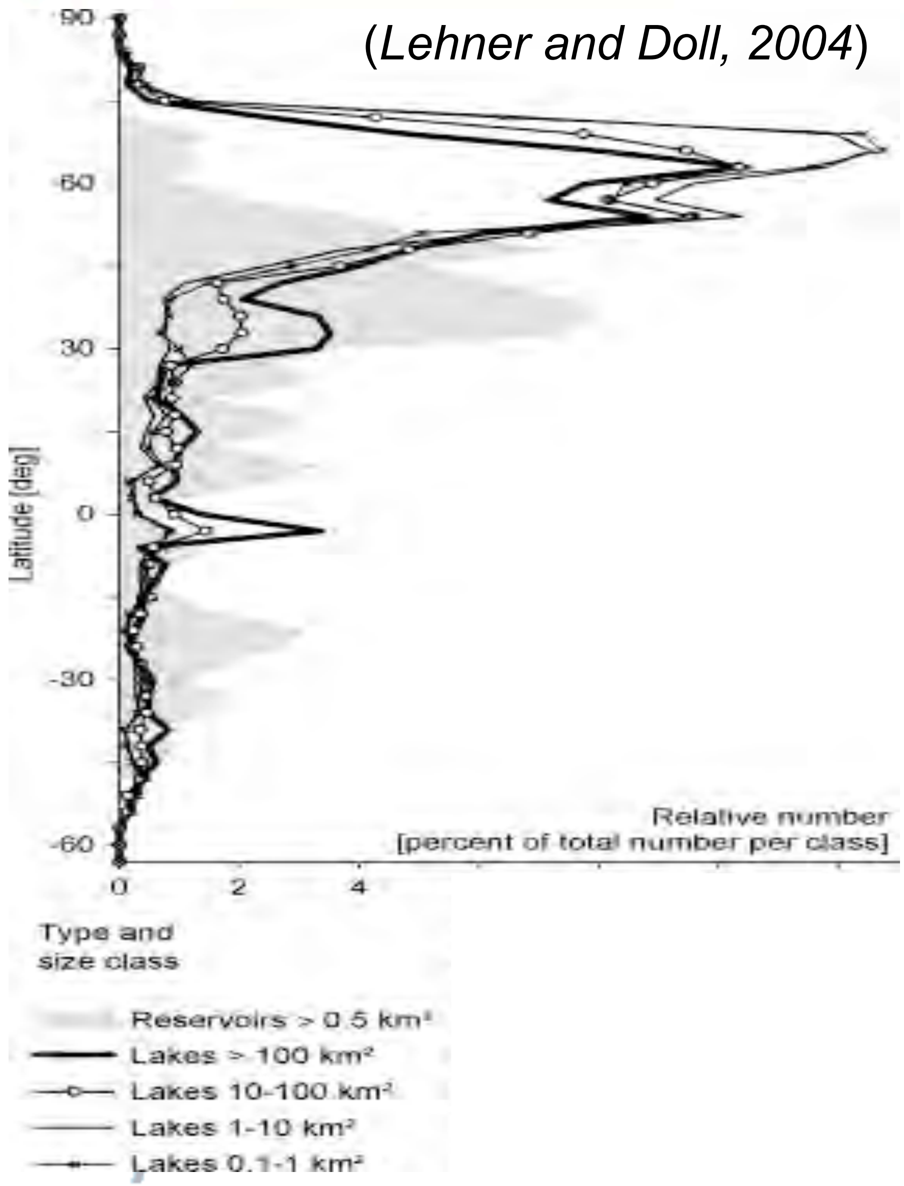
- national hydrological services and decision makers
- international institution and programs: WMO, GEO, GIEC, ILEC, ICOLD ...
- Interstate Commission for Water coordination: IFAS (Central Asia), Commission for Lakes Titicaca or Geneva, IJC (Canada/US) …..
- Hydrologists, and climatologists….

SWOT *Science and Applications* → 3 Lakes, Wetlands



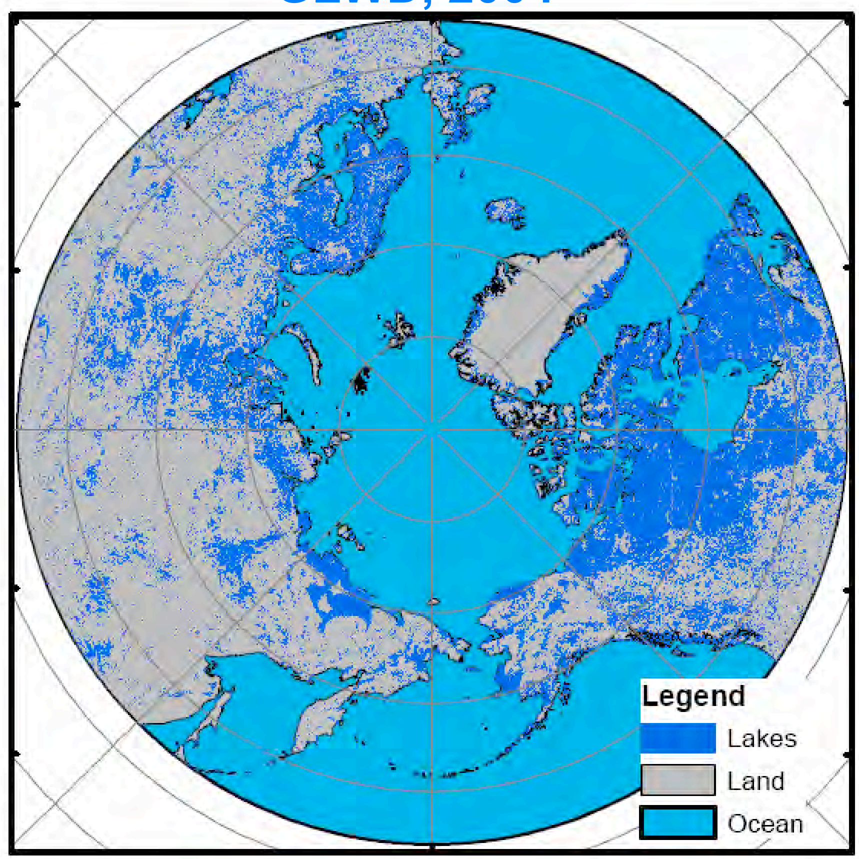
- Pan-Arctic: 1st peak
- Tibetan Plateau: 2nd peak

SWOT *Science and Applications* ➔ 3 Lakes, Wetlands

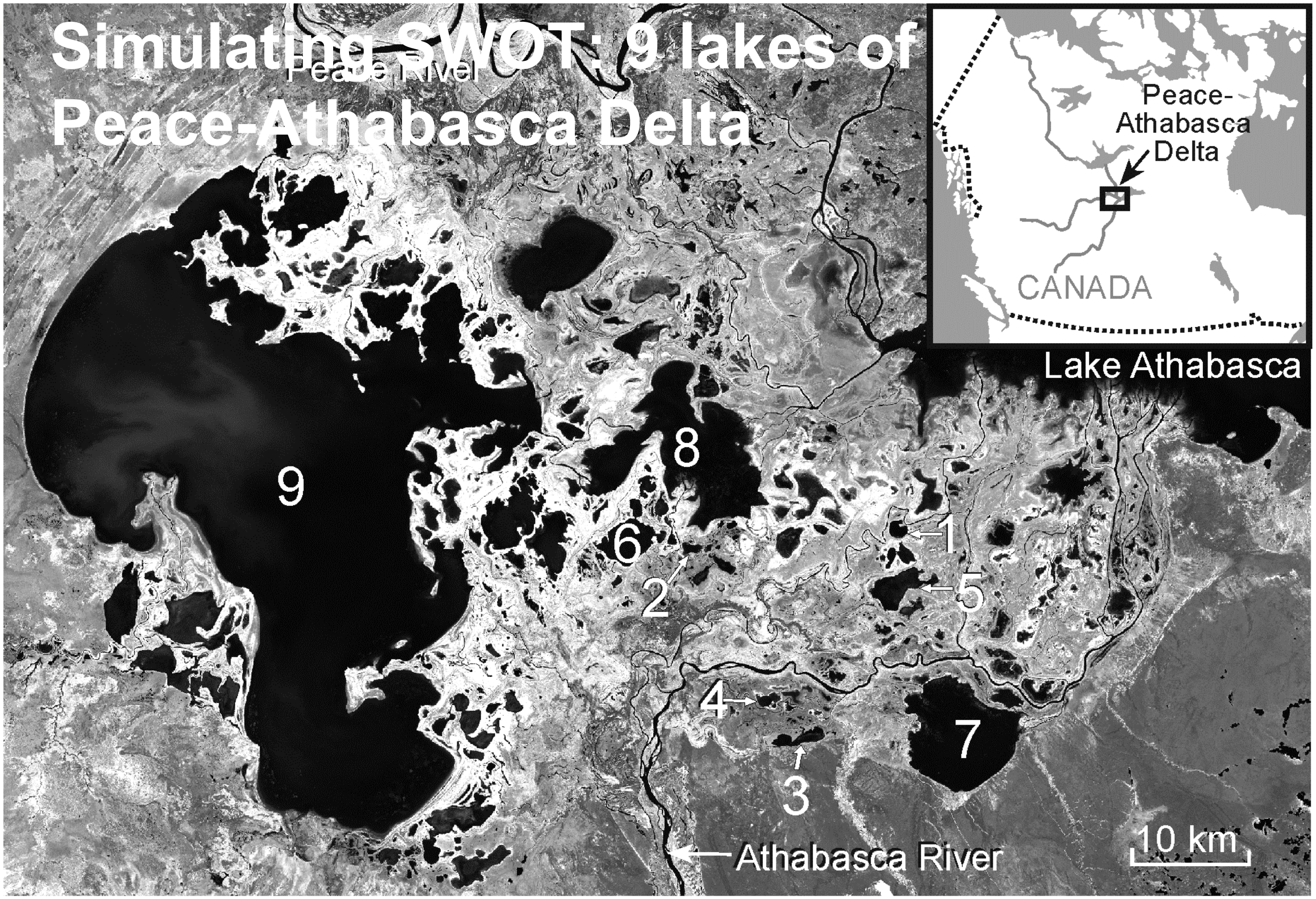


- Pan-Arctic: 1st peak
- Tibetan Plateau: 2nd peak

GLWD, 2004



SWOT Science and Applications → 3 Lakes, Wetlands



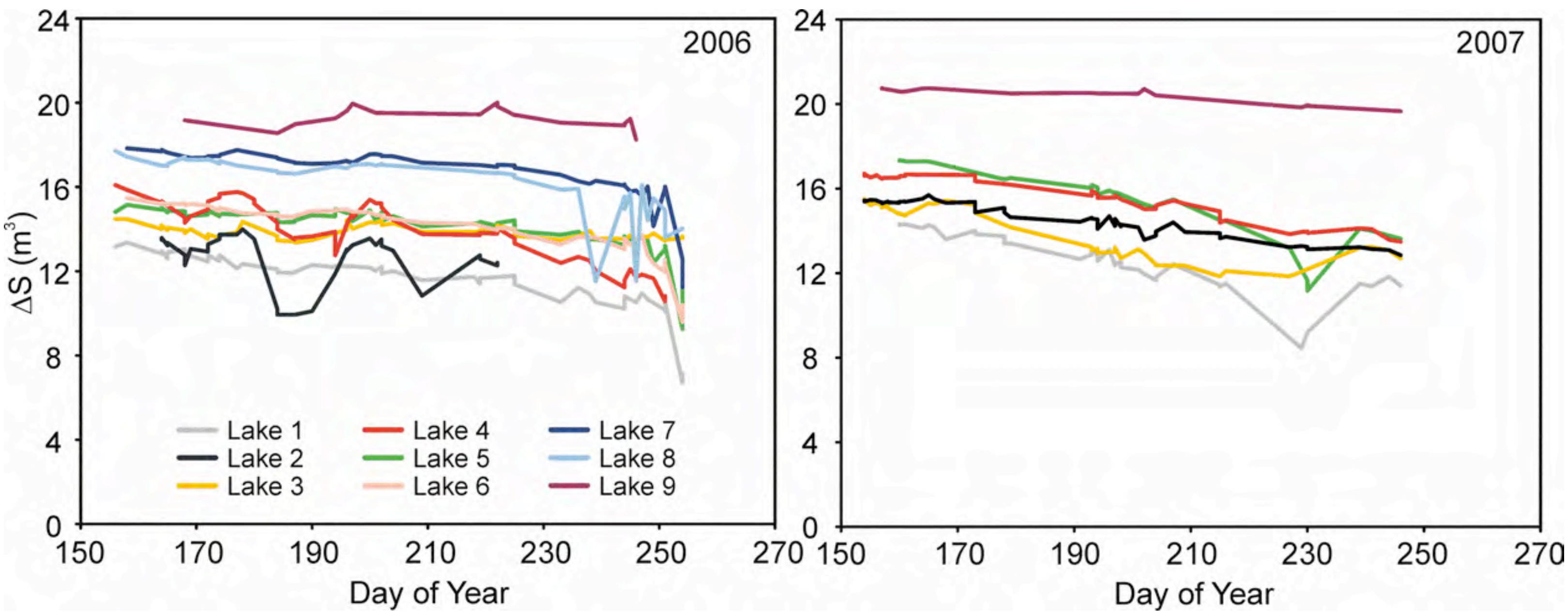
T. Pavelsky,
L. Smith

SWOT Science and Applications → 3 Lakes, Wetlands

$$(A_t)(dH/dt) = dS/dt$$

A_t: MODIS

dH/dt: ground



(~200 – 500,000 m^3)

SWOT *Science and Applications* ➔ 3 Lakes, Wetlands

- Northern high latitudes are wet, unknown, and important.

- Precision of SWOT retrievals (*dS/dt; dQ/dt*) will vary with hydraulic geometry from lake to lake and even along the same river-course. This issue has not been addressed by VM-type simulation studies.

- *“It’s not just the specs of the satellite that matter - it’s the specs of the SITE”* (L. Smith)

- Potential solutions: First-order area correction (lakes); building empirical rating functions over the mission lifetime for each & every SWOT target (i.e. a map of A/dH, A/dQ regression slopes); and scaling amount of multi-looking accordingly.

SWOT Science and Applications → 3 Lakes, Wetlands

SWOT- lakes/wetlands in tropical regions:

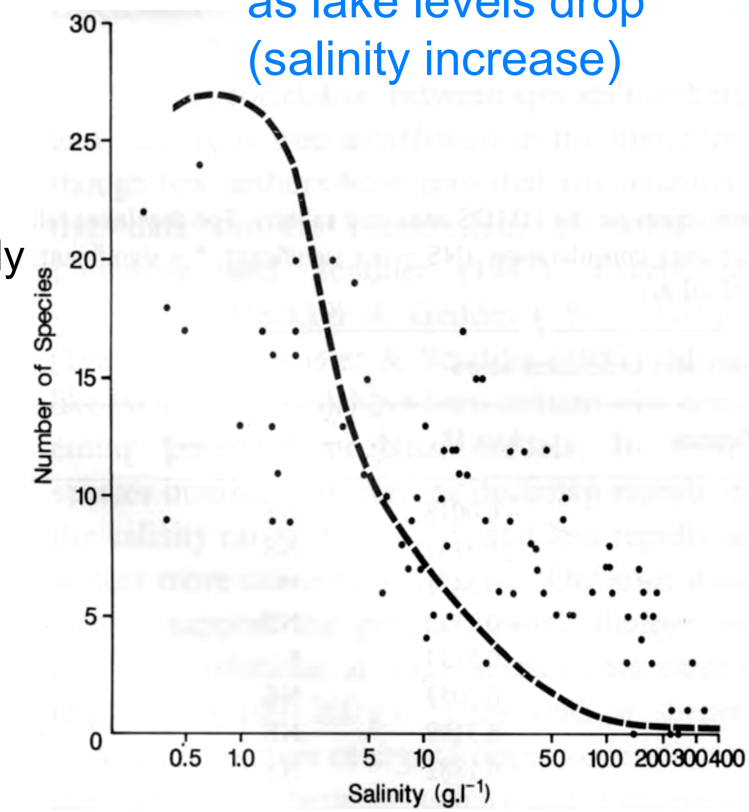
Lake levels variations throughout a region in lakes of a wide range of sizes ➔ an indication of climatic changes (consequences for biological diversity and productivity)

Large lakes ➔ evidence for internal wave activity and eddy structures as indications of mixing with consequences for productivity

Water level variations in reservoirs ➔ a measure of water resources and hydroelectric power potential

dH/dt, dH/dx ➔ driver of hydrologic exchanges and movements of sediments, solutes, pollutants and organisms with consequences for primary and secondary productivity

Biodiversity decreases as lake levels drop (salinity increase)



(Williams, Boulton & Taaffe 1990 Hydrobiologia 197:257-266)

SWOT *Science and Applications* ➔ **3 Lakes, Wetlands**

Mid-latitude: Prairie Pothole Region

- Unique lake system Canada and USA
- Upwards of **6 million** pothole lakes
- Most located around edges with more rainfall
- Important farming impacts
- Biodivsersity ➔ Breeding grounds for 60% of North American duck species

- Challenge for hydrologists ➔ describing and understanding processes in large complex systems
- **Conventional monitoring approaches inadequate and not commonly available**
- Tremendous potential in linking regional-scale models and remote sensing
- SWOT provides important new capabilities

The Need for Integrated Water Cycle Modeling

- Modeling all the major stocks and fluxes of the terrestrial water cycle in a comprehensive and interactive manner.
  - Snow, surface water, soil moisture, groundwater
  - Evapotranspiration, runoff, streamflow, floodplain hydrodynamics, energy fluxes, interfacial water fluxes
- Links to *in situ* and remotely-sensed data, hydrologic information systems, etc.
  - Streamflow, soil moisture, well levels
  - **SWOT**, SMOS, SMAP, GRACE, AMSR-E, MODIS, etc.
- Ideally, water management, consumptive use and urban areas should be included
  - Irrigation, reservoir storage, withdrawal rates
- Links to water quality, biogeochemical, ecological and climate models
- Models should be available to the community
  - Community Hydrologic Modeling Platform (**CHyMP**) J. Famiglietti

Potential Applications of Integrated Water Cycle Modeling

What questions can we address with such models?

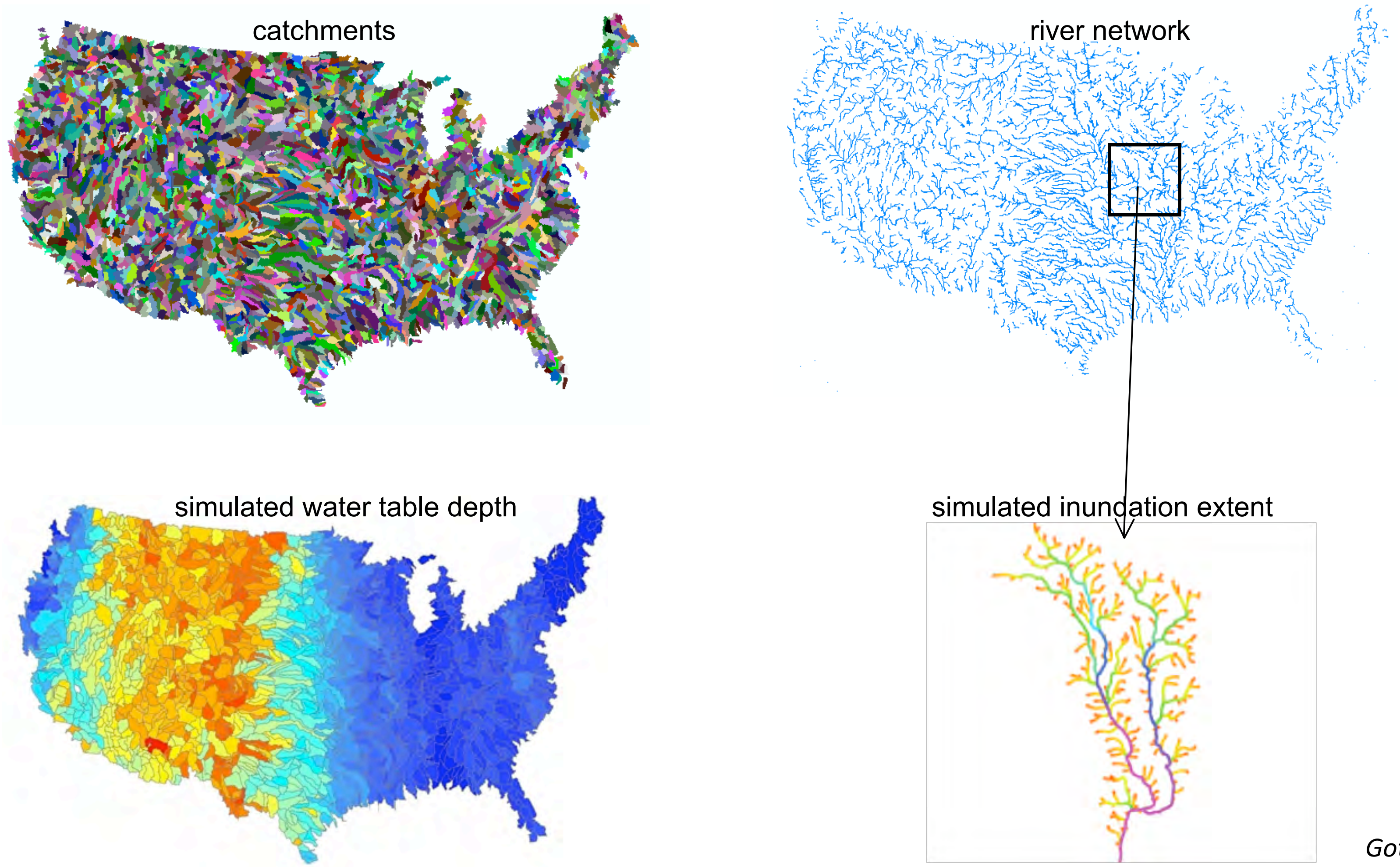
- How is fresh water distributed over and through the land surface, and how will this change over the next century?
- How can water management best adapt to changes in global hydrology, and what are the local- to global-scale feedbacks?
- Is enhanced terrestrial water storage a viable strategy to mitigate sea level rise while relieving potential water availability in drought-prone regions?

Grand challenge: modeling the storage, movement and quality of water at every point on the landscape

There is simply no way to accomplish this without assimilation of in situ and remotely sensed data

An Integrated Water Cycle Model

The need for SWOT and other sensors



Goteti et al., 2008

General Problem of Transboundary Flow Forecasting in the Developing World: The Niger River

1. 4030 km long, 2,113,200 km^2

2. Flows through 5 countries

3. Drainage area comprised of 11 countries

4. Frequent river flooding induced by heavy rainfall

5. Diverse climate, rainfall regime, soil conditions, topography = varying response of landscape to rainfall

How does a downstream nation monitor early the evolution of river flow across political boundaries of 5 nations, 11 administrations and a diverse landscape?

F. Hossain

Transboundary Flow Forecasting: The Global Picture on International River Basins

- Hydro-political limitations worsen at the shorter time scales

Percentage Area (of an IRB)	Number of Countries
91-99%	39
81-90%	11
71-80%	14
61-70%	11
51-60%	17
41-50%	10
31-40%	10
21-30%	13
11-20%	9
1-10%	11

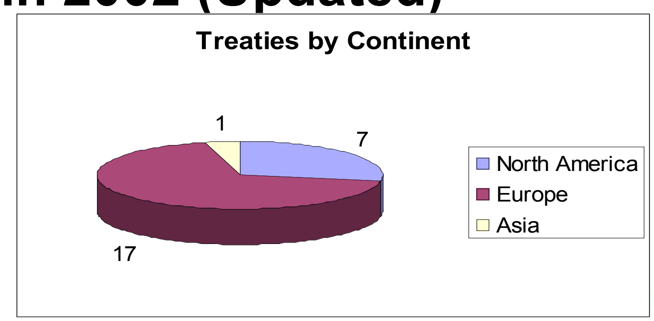
Source: Dr. Aaron Wolf, Oregon State University

145 countries are associated in IRBs..

> 50% of total surface flow

214 International River Basins in 1979 UN Register

261 in 2002 (Updated)



Distribution of treaties with allusion to transboundary flood management

F. Hossain

SWOT *Science and Applications* ➔ Summary

• SWOT does not represent a gauge replacement strategy! But, discharge at a given accuracy can be a level II product…

• Hydrodynamic models are typically tested/developed on a limited number of case studies….SWOT will help immensely. Also, could make 2D modelling routine globally!

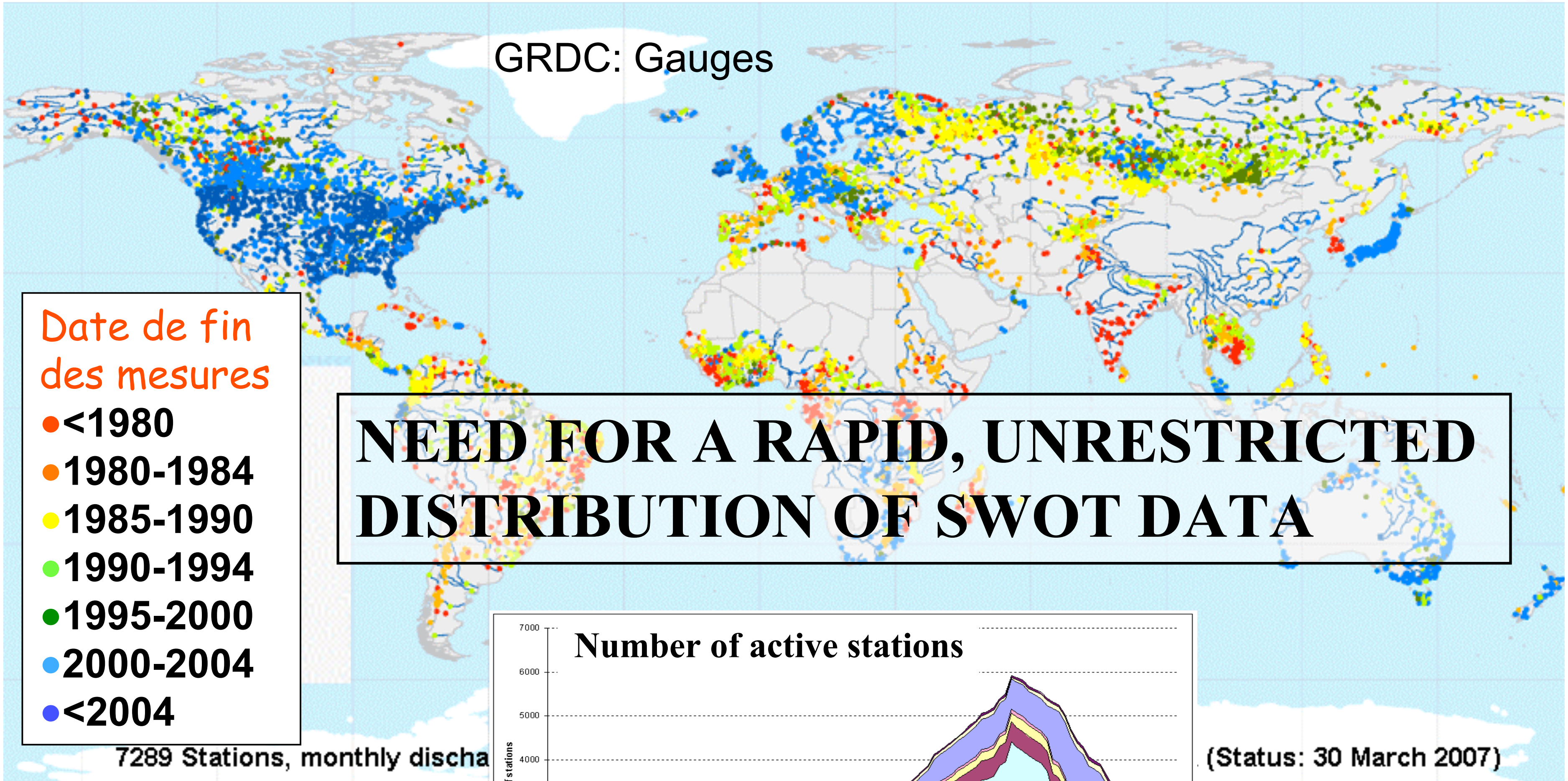
• Hydrological-Hydrodynamic models need global datasets of required input parameters (e.g. river width…), evaluation

• Lake inventory, dynamics, interactions with flooded zones

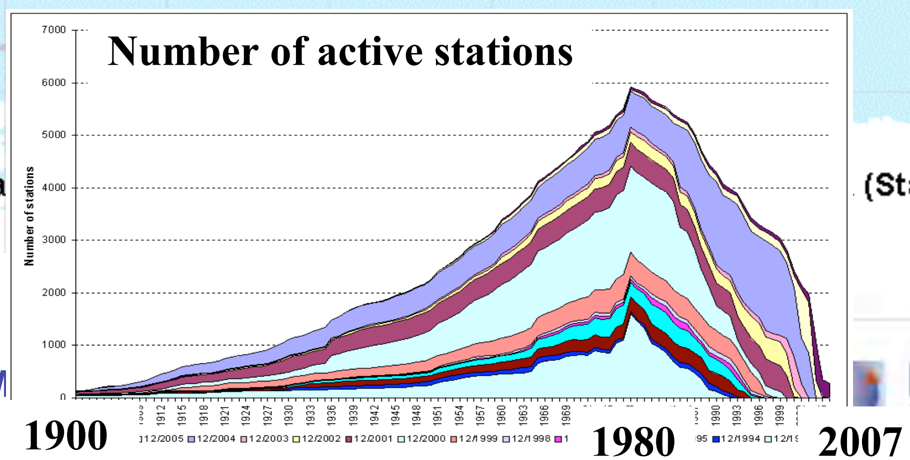
• Improved representation of hydrological/hydrodynamic & lake processes for use in RCMs and GCMs (scenarios with potential feedbacks): lake changes, methane release…

• Societal issues: improved mapping of flood risk zones, trans-boundary river basin issues, reservoir monitoring

SWOT *Science and Applications*



NEED FOR A RAPID, UNRESTRICTED DISTRIBUTION OF SWOT DATA



CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

METEO FRANCE
Toujours un temps d'avance

SWOT Science and Applications → Summary

• SWOT does not represent a gauge replacement strategy! But, discharge at a given accuracy can be a level II product…

• Hydrodynamic models are typically tested/developed on a limited number of case studies….SWOT will help immensely. Also, could make 2D modelling routine globally!

• Hydrological-Hydrodynamic models need global datasets of required input parameters (e.g. river width…), evaluation

• Lake inventory, dynamics, interactions with flooded zones

• Improved representation of hydrological/hydrodynamic & lake processes for use in RCMs and GCMs (scenarios with potential feedbacks): lake changes, methane release…

• Societal issues: improved mapping of flood risk zones, trans-boundary river basin issues, reservoir monitoring

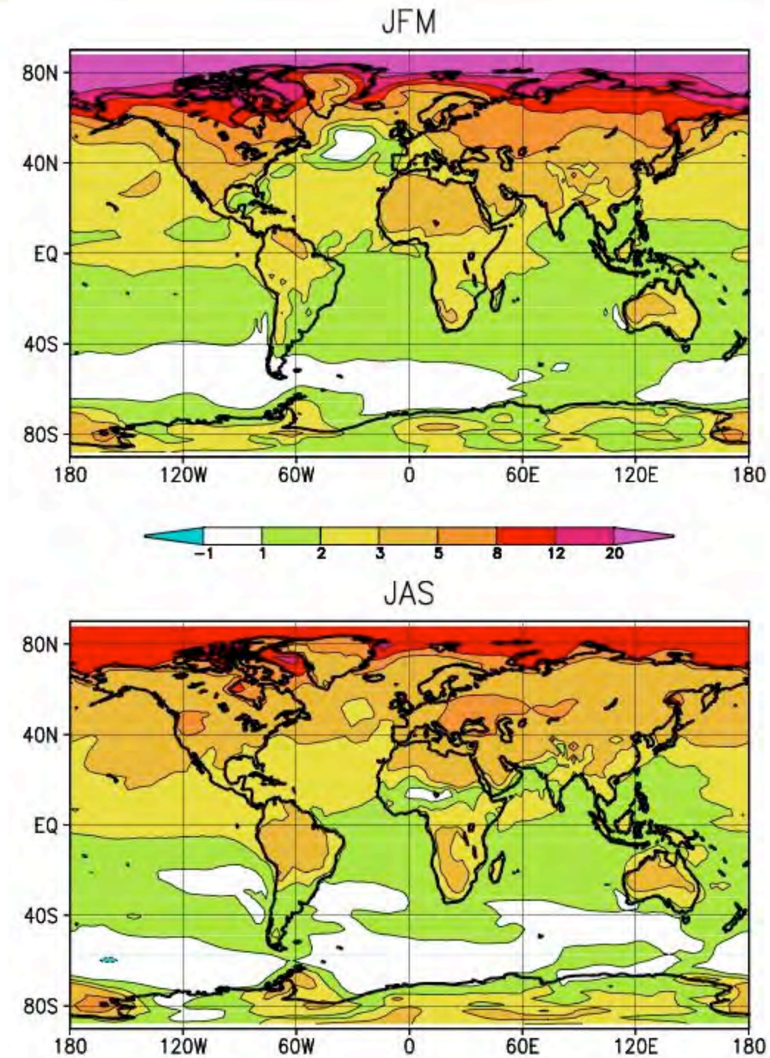
SWOT *Science and Applications*

<u>Cimate Projections</u>:

SWOT data esp important a high lats in the context of projected climate change: a sample of IPCC Météo-France results…(B2 scenario)

Significant Change in regimes for:

- Wetlands, flooded zones
- Lakes
- Discharge (potenial feedbacks with ocean and ice….)
- Wetland Carbon, Methane emssions…



Need global scale data to develop & improve parameterizations for useful climate projections of hydrological impacts!

SWOT Science and Applications → Summary

• SWOT does not represent a gauge replacement strategy! But, discharge at a given accuracy can be a level II product…

• Hydrodynamic models are typically tested/developed on a limited number of case studies….SWOT will help immensely. Also, could make 2D modelling routine globally!

• Hydrological-Hydrodynamic models need global datasets of required input parameters (e.g. river width…), evaluation

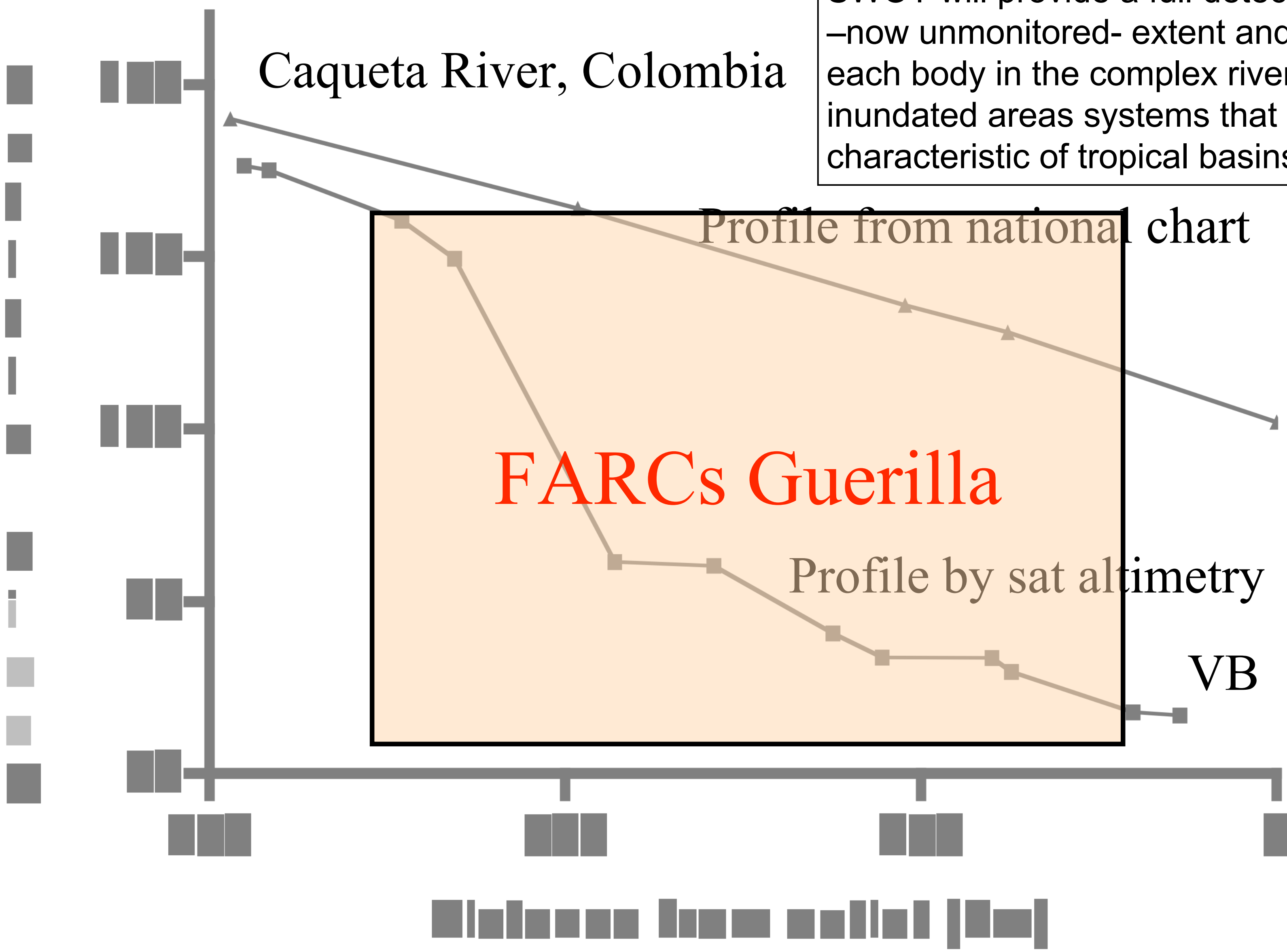
• Lake inventory, dynamics, interactions with flooded zones

• Improved representation of hydrological/hydrodynamic & lake processes for use in RCMs and GCMs (scenarios with potential feedbacks): lake changes, methane release…

• Societal issues: improved mapping of flood risk zones, trans-boundary river basin issues, reservoir monitoring

SWOT: High resolution of river altitude profile

SWOT will provide a full detection of the –now unmonitored- extent and level of each body in the complex river-wetland-inundated areas systems that are characteristic of tropical basins.



fin…